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Effects of magnitude-frequency distribution on debris-flow avulsions and fan development

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Shifts in the active channel on a debris-flow fan, termed avulsions, pose a large threat because new channels can bypass mitigation measures and cause damage to settlements and infrastructure. Recent, but limited, field evidence, from for example the Kamikamihori fan in Japan, suggests that avulsion processes and tendency may depend on the debris-flow magnitude-frequency distribution.

Here, we create three experimental fans with contrasting flow-size distributions to investigate how the distribution and the associated flow-magnitude sequences affect avulsion on debris-flow fans. Fan 01, formed by debris flows of uniform size, developed through regular sequences of stepwise channelization, backstepping of deposition toward the fan apex, and avulsion over multiple flows. In contrast, on fans 02 and 03, formed by double-Pareto distributions with different power-law tail exponents, the variability of flow sizes led to distinct avulsion mechanisms and fan evolution. On these fans, large flows could overtop channels, initiate avulsion, and form new channels within a single event, while avulsions on fan 01 always developed over multiple events. Avulsions on fans 02 and 03 also proceeded through sequences of small- to moderately-sized flows that deposited channel plugs, triggering avulsion in the next large flow. This mechanism was most common on fan 02, which was formed by a steep-tailed double-Pareto distribution with proportionately more small flows, but was rare on fan 03, where the distribution had a shallower tail and where very large flows were more frequent.

Based on these results, we speculate that some flow-size distributions promote avulsion while others do not, largely because of the likely flow-magnitude sequences associated with these distributions. This finding has important implications for hazard mitigation and fan evolution, suggesting for example that a sequence of small flows followed by a large flow is likely to cause avulsion, and emphasizes the need to further explore relationships between flow-magnitude sequences and observations of avulsion on debris-flow fans.